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Instant Hot Water Heater

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By

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Abstract

One of the first steps in the beer brewing process is to heat water to a specific temperature before it is mixed with the malt. The purpose of this project was to make a more compact and efficient heating device for the beer brewing process. The output temperature must be between 170ºF and 180ºF. The minimum flow rate should be half a gallon per minute with the maximum flow rate of three gallons per minute. The device will also need to mount to a collapsible beer rack being designed by Andrew Kastning. The device will be primarily compromised of two 2 inch steel square tubes welded forming an L shape, a burner, coiled copper pipe and a cover made of stove pipe for the coils that will be mounted to the L shape welded steel square tubes and above the burner. Analysis was completed to determine the optimal size of copper tubing to most efficiently heat the water. Three-eighth inch copper pipe was selected for the coil. Upon testing the device the flow rate was able to be dialed down between one half and three gallons per minute while staying in between the desired temperature range of 170ºF and 180ºF.

Introduction

Motivation

A collapsible beer rack will be made but there should be another way to shorten the process of brewing beer that will also be a part of the beer rack. The first step to brewing beer is to heat water to a specific temperature then that water is mixed with the malt. This first step is to be made to be more compact and quicker than the current method in heating the water to a specific temperature.

Function Statement

The device must produce a constant flow of hot water at a specific temperature range.

The device must have some sort of flow control and able to measure the rate of flow.

Requirements

In order to be successful this design must meet the following requirements:

- The flow must be at a temperature between 170 F and 180F.
- The minimum flow rate should be 0.5 gallons per minute.
- The maximum flow rate should be 3.0 gallons per minute.
- The device must weigh less than 15 pounds.
- This must cost less than $300.
- The device needs to be compact enough to be able to mount on the collapsible beer rack.
- The device must have some sort of flow control and able to measure the rate of flow.

Engineering Merit

This project will require several analyses. Equations for flow from the water heater to the next step of the brewing process, the heat transfer to keep the water at the specified temperature range.

Scope of Effort

There will be two different types of instant hot water heaters in addition to a collapsible beer rack that the heater will be mounted to. This project is only dealing with one of the water heaters.

Success Criteria

- The device heats water to the required temperature in a smaller amount of time.
- The device is small enough to fit onto the collapsible beer rack without interfering with other parts of the beer rack.
- The total amount of water flow is able to be controlled to a specific point.

Design and Analyses

Approach: Proposed Solution

One of the requirements of the hot water heater is to achieve an output flow rate between 0.5 to 3.0 gallons per minute. In order to achieve this the length of piping needs to be determined. With the length of piping the amount of energy to heat the piping will be calculated.

Design Description

The hot water heater will comprise of a coiled copper piping, a burner, a cover for the coil of piping, a throttling valve for both the input and output of the piping and a propane fuel source for the burner. There will be a mount of two-inch square tubing on the beer rack so that the burner can be placed on the mount and mounted to it as well. The coiled copper piping will rest horizontally inside the cover with the output of the piping coming through the cover over the burner.

Benchmark

A typical burner that produces 54,000 BTU should boil a 15.5-gallon pot of water in about 41 minutes assuming a fifty percent efficiency.

Performance Predictions

For the ¼ inch pipe it is calculated that the overall maximum length of piping required is 85.126 feet. For the 3/8 inch pipe it is calculated that the overall maximum length of piping required is 83.28 feet. For the ½ inch pipe it is calculated that the overall maximum length of piping required is 95.935 feet. The energy required for the ¼ inch pipe should be 68574 BTU/hr. The energy required for the 3/8-inch pipe should be 202920 BTU/hr. The energy required for the ½ inch pipe should be 419832 BTU/hr.

Description Analyses

In order to find the length of copper piping a standard size pipe size must be selected. A ¼ inch, 3/8 inch and ½ inch pipe diameter will be evaluated to determine the pipe length and amount of energy required to heat the piping.

Scope of Testing and Evaluation

To test this project a temperature sensor will be needed to determine if the water heats to the desired temperature. A flow meter will be needed to test the output flow from the hot water heater to the next pot in the beer brewing process.

Analyses

Design Issue

The length of the piping and amount of energy required to heat the coiled piping need to be determined.

Calculated Parameters

From Appendix 2 table A-15E of the Fundamentals of Thermal Fluid Sciences book, the properties of water at 50 degrees Fahrenheit and 190 degrees Fahrenheit are documented as in Appendix A-1. From engineeringtoolbox.com a graph that compares water pressure and water discharge in gallons per minute based on different nominal hose diameters is used to find the expected water discharge from a 100-foot hose. The water pressure inlet is assumed to be 40 psi based on the average inlet pressure from a hose in a house. Using the equation in Appendix A-1 and A-2 each of the flow rates from the graph are converted from gallons per minute to a velocity in feet per second. With the velocities for all three sizes of piping the Reynolds numbers is determined seen on Appendix A-3. From table 14-2 page 553 of the Fundamentals of Thermal

Fluid Sciences book the roughness is given for copper and then converted from feet to inches. Next the Moody chart in Appendix 1, figure A-27 from the Fundamentals of Thermal Fluid Sciences book is used to determine the Darcy friction factor for each copper pipe size. Next the maximum pipe length is determined for each of the standard pipe sizes as calculated on Appendix A-4. The energy to heat the water from 50 to 190 degrees Fahrenheit is calculated on Appendix A-5 based on the maximum flow rate in each standard size piping. With the energy determined from Appendix A-5 the ideal length of the pipe is calculated as shown on Appendix A-6 for the maximum flow rate of the water. The energy to heat the water from 50 to 190 degrees Fahrenheit for the standard size pipes at 0.5 gpm, 1.0 gpm, 1.5 gpm and 3.0 gpm seen on Appendix A-7. All of the used flow rates are within the design requirements of hot water output. With the energy calculations at the specific flow rates stated the length of the pipes for each standard size were calculated for the previously specified flow rates as seen on Appendix A-8 through A-11. With these calculations, an overall length of 20 feet and 3/8 inch pipe size was selected for the design.

The height of the coiled piping was then determined so that mounting sizes could be determined. During the calculations, a non-integer value of 12.73 coils was found based on the 20-foot length of the piping circumference of one coil so the number of coils was rounded up to 13 coils, and the overall length of the piping was changed to 20.423 feet. With these numbers, the height was calculated to be 8.124 inches all seen on Appendix A-12.

Device: Parts, Shapes and Conformation

The burner will be connect to a fuel source with the coiled copper piping resting horizontally above the burner so that it will be heated with the output of the piping coming through the cover over the burner. The cover for the piping will cover the piping, but will allow for a hose to attach to the inlet of the piping and the outlet of the piping will be exposed so that a throttling valve can be attached to maintain a specific flow rate.

Device Assembly, Attachments

Two one-foot-long two-inch square steel tubes will be assembled and attached to the three-inch square tubing of the beer rack. The coil will rest horizontally above the burner so that it will be heated with the output of the piping coming through the cover over the burner.

Tolerances, Kinematics, Ergonomics

The temperature of the water after being heated may be between 170 F and 180 F. The output flow rate may be between 0.5 and 3.0 gallons per minute.

Technical Risk Analysis, Failure Mode Analyses, Safety Factors, Operation Limits

In calculating the pressure drop in the device the inlet pressure of 40 psi is selected for a worst case scenario as many homes have a water pressure from their hoses less than the 40 psi used.

Methods and Construction

Construction

The construction of the device is expected to order the parts necessary and to assemble the device to the design requirements. There will be thirteen coils in the coiled copper piping with a total height of 8.124 inches and a diameter of the coil of 6 inches.

Description

The coiled copper piping will be placed horizontally above the burner so that it will be heated with the output of the piping coming through the cover over the burner. The burner will connect to a fuel source and the cover for the device will be placed over the coiled copper piping, but will attach to the burner so that the entire device is connected. A three-eighth inch hole will be drilled into the cover so that the outlet of the copper piping can come through the cover. A slit will also be cut on the outside of the cover so that the inlet of the copper piping can rest without displacing from its position. The coil will be placed inside the cover with bolts and nuts holding it into place both vertically and horizontally.

Manufacturing issues

The main issue seen in this project is designing, building and attaching the cover to the burner so that the coils will not move or be displaced.

Discussion of assembly, sub-assemblies, parts, drawings (examples)

Two one-foot-long two-inch square steel tubes will be cut at a 45 degree angle and welded together to form an L shape as seen in Appendix B-2 attached to the two-inch square tubing of the beer rack. The coil will rest horizontally above the burner so that it will be heated with the output of the piping coming through the cover over the burner.

Testing Method

Introduction

The primary things that need to be tested for the device are the temperature of the water from heating, the amount of time it will take for the water to heat up to the desired temperature range and the output flow rate of the water so that it is in the desired range.

Method/Approach

In order to test the temperature of the water a temperature sensor is needed. In order to test the flow rate a gallon bucket and a timer are needed. The timer will also be used to measure the amount of time to heat the water to the 170 F – 180 F temperature range. Table G-1 in Appendix G show the data sheet used to record the different trials and converting the gallons per second to gallons per minute

Test Procedure

The temperature sensor will show how hot the water is while the timer will be used to see how long it takes to heat the water to the desired temperature range as well as to measure the output flow rate.

Test 1: Temperature

The test will take a maximum of five minutes after initial set up is complete.

Along with the Instant Hot Water Heater, a table that can withstand high heat temperatures, a metal clamp, a propane tank, a lighter, a hose that supplies water, a large bucket and a thermometer will be used to run and test this device.

Steps:

1. Clamp the device to the table. The side parallel with and furthest away from the heater should be clamped.
2. Place the outlet tube into the large bucket.
3. Connect the hose to the inlet of the copper piping.
4. Connect the burner to the propane tank.
5. With both ball valves all the way open, turn on the water from the hose.
6. Open the valve for the propane and open the valve for the burner as well. (Make sure the maximum amount of air flow is allowed into the burner by adjusting the plate at the end of the burner.
7. Light the burner through the opening where the coils are seen.
8. Once the burner has been lit, time how long it takes the water to heat to the desired temperature range of 170F-180F.
9. Adjust the ball valves to dial down the flow rate of the water until the desired temperature is reached. Do not shut the inlet ball valve and make sure enough water is flowing through the coils to ensure some flow out of the outlet pipe.
10. Using the thermometer, measure the temperature of the outlet water.
11. Turn off the burner, close the propane tank and let the device cool for at least two hours.
12. Repeat steps 1-11 four more times.

Safety:

Safety glasses should be worn at all times during the test of this device. Use caution when lighting the burner so injury does not occur.

Test 2: Output Flow Rate

The test will take a maximum of five minutes after initial set up is complete.

Along with the Instant Hot Water Heater, a table that can withstand high heat temperatures, a metal clamp, a propane tank, a lighter, a hose that supplies water, a one-gallon bucket and a timer will be used to run and test the device.

Steps:

1. Clamp the device to the table. The side parallel with and furthest away from the heater should be clamped.
2. Place the outlet tube into the large bucket.
3. Connect the hose to the inlet of the copper piping.

4. Connect the burner to the propane tank.
5. With both ball valves all the way open, turn on the water from the hose.
6. Open the valve for the propane and open the valve for the burner as well. (Make sure the maximum amount of air flow is allowed into the burner by adjusting the plate at the end of the burner.
7. Light the burner through the opening where the coils are seen.
8. Adjust the ball valves to dial down the flow rate of the water until the desired temperature is reached. Do not shut the inlet ball valve and make sure enough water is flowing through the coils to ensure some flow out of the outlet pipe.
9. Once the desired temperature is reached, empty the one gallon bucket and time how long it takes to fill the one gallon bucket completely in seconds. Convert this number from seconds to minutes to get the flow rate in gallons per minute.
10. Repeat step 9 four more times at different temperatures while still staying within the 170F-180F temperature range.

Deliverables

The temperature of the water after being heated, the time to heat the water to the desired temperature range and the flow rate of the water output from the device will all be able to be determined to meet the design requirements.

As seen in Appendix I, the device was able to reach the desired temperature range while also maintaining an output flow rate between the desired range of 0.5 GPM and 3.0 GPM.

Budget/Schedule/Project Management

Proposed Budget

This project will require 20.423 feet of coiled copper piping costing $47.00 per 20 feet of piping. A burner from morebeer.com will cost $17.99. The burner will be fueled by a tank of propane that costs around $20 to exchange an empty one for a full one. Two one foot long two inch steel square tubes will be needed for the attachment to the made collapsible beer rack. Ball valves with compression fittings on both the inlet and outlet ends of the piping will be needed to control the flow rates of the water. Each valve cost ten dollars. A stove pipe cover will be used costing about $69.00 as well. A temperature sensor will also be needed and is included on the full budget in Appendix Table D-1.

Proposed Schedule

This project will start in late September and will finish at the end of spring quarter in June. In order to be complete on time all drawings and calculations must be completed before the proposal is submitted. Future dates for the scheduled were estimated so that an ideal time range can be seen on when the project will be complete. The total amount of time expected to be put into this project is 159 hours including the proposal, manufacture plan, completion of the device, the testing plan, the evaluation of the device and the full project report. The full proposed schedule can be seen in Appendix E Figure E-1.

Project Management

Of the parts needed for this project only one of the items will be donated. The rest will be bought or will be supplied for use by CWU. The burner will be from morebeer.com. The list of parts and sources can be seen in Appendix C Figure C-2.

Discussion

To begin the process a project idea was desired to use some sort of heat transfer topic. With the need to make a device to quicken the beer brewing process the project was selected to be an instant hot water heater. The design requirements were made to evaluate if the device would in fact be quicker and more precise in the first step of the brewing process.

In calculating the length, and size of piping several steps were taken. An input flow rate was determined from engineering toolbox for a 100-foot hose at 40 psi. The flow rate was converted from gallons per minute to feet per second in order to calculate the Reynold's number for each size of pipe. After finding the Reynold's number the maximum length of the piping was calculated with the formula $L = \frac{2*\Delta P_L*D}{\rho*v^2*f}$ where ΔP_L is the desired pressure loss, ρ is the density of water at 50 ^{0}F, D is the diameter of the piping, v is the average velocity previously calculated and f is the Darcy friction factor. The amount of energy needed to heat the water and ideal length were then calculated, but later were recalculated since the first calculations were for maximum flow rate. With the calculated length and energy required to heat the water the size of piping and length were selected for the project. The height of the piping was calculated based on the inside and outside diameters of the piping and the diameter of the coil. A non-integer number of coils was calculated so the number was rounded up changing the overall length of the piping also changing the height of the coiled copper piping.

When coming up with a design several setups were discussed until deciding on a coiled copper piping resting on a burner would be the official design. The design however changed from that to resting the coiled copper piping horizontally and having the burner make two passes through the system. Where the burner is attached to a mount from the collapsible beer rack. This design was changed again to eliminate heat loss. A quarter inch rod replaced the top horizontal steel square tube. This design was changed again to a 6" stove pipe cover to be used as the cover for the coils placed horizontally and fixed with nuts and bolts to keep the coils in place.

Conclusion

An instant hot water heater has been thought up, analyzed and designed to meet the design requirements previously stated. Parts have been documented along with an accompanying budget. With this information, the instant hot water heater was constructed and tested. This project meets the requirements of a successful senior project such as; having substantive engineering merit in heat transfer, the size and cost of the instant hot water heater is within the limits of our resources and is of great interest to the investigator.

Acknowledgements

Thank you to Professor Beardsley, Professor Pringle and Dr. Johnson for their support and help in mentoring in this project. Thank you to Central Washington University for use of parts and the shop in this project. Thank you to Tiago Sousa and Stefan Schacht for their help in the welding of my parts.

Appendix A-Analyses

Given: $T_{water,hose} = 50°F$, $T_{water,out} = 190°F$
$P_1 = 40\,psia$ (average pressure from house)
$P_2 = 5\,psia$

Find: Length, material, standard size piping

Sol'n:

From Appendix 2 table A-15E of Fundamentals of Thermal Fluid Sciences:

water @ 50°F: $\rho = 62.41\ lbm/ft^3$
$c_p = 1.000\ BTU/lbm \cdot R$
$\mu = 8.781 \times 10^{-4}\ lbm/ft \cdot s$
$Pr = 9.44$

water @ 190°F: $\rho = 60.35\ lbm/ft^3$
$c_p = 1.004\ BTU/lbm \cdot R$
$\mu = 2.169 \times 10^{-4}\ lbm/ft \cdot s$
$Pr = 2.01$

From table 14-2 pg 553:

roughness, ε, for copper tubbing $= .000005 ft \cdot \frac{12 in}{1 ft} = .00006\ in$

From engineering toolbox graph for a 100 ft hose

$\frac{1}{4}$ in diameter: @ 40 psi gpm ≈ 0.98 gpm $\Rightarrow 0.40\ psi/ft$
$\frac{3}{8}$ in diameter: @ 40 psi gpm ≈ 2.90 gpm
$\frac{1}{2}$ in diameter: @ 40 psi gpm ≈ 6 gpm

@ max flow rate

Converting gallons per minute to feet per second, U_{avg}

$$in^3 = 1 gal \times 231 \frac{in^3}{gal}$$

$$\frac{in^3}{min} = \frac{1 gal}{min} \times \frac{231 in^3}{gal}$$

$$(Area\ in^2) \times \frac{in}{min} = \frac{1 gal}{min} \times \frac{231 in^3}{gal} \therefore \frac{in}{min} = \frac{\frac{gal}{min} \times \frac{231 in^3}{gal}}{(Area\ in^2)}$$

$$in/min = \frac{ft}{sec} \times in/ft \times \frac{sec}{min}$$

$$= \frac{ft}{sec} \times \frac{12 in}{1 ft} \times \frac{60 sec}{min} \Rightarrow ft/sec = \frac{in/min}{\left(\frac{12 in}{ft} \times \frac{60 sec}{min}\right)}$$

$$\frac{\frac{in}{min}}{\left(\frac{12 in}{ft}\right)\left(\frac{60 sec}{min}\right)} = \frac{\frac{gal/min \times 231 \frac{in^3}{gal}}{(area\ in^2)}}{\left(\frac{12 in}{ft}\right)\left(\frac{60 sec}{min}\right)}$$

$$\frac{ft}{sec} = \frac{\frac{gal}{min}}{(Area\ in^2)} \times \frac{231 \frac{in^3}{gal}}{\left(12 \frac{in}{ft} \cdot \frac{60 sec}{min}\right)}$$

$$= \frac{gal/min}{(Area\ in^2)} \times .32083 \frac{in^3 \cdot ft \cdot min}{gal \cdot in \cdot sec}$$

$$V_{avg_{1/4}} = \frac{gpm}{Area} \times .32083 \frac{in^3 \cdot ft \cdot min}{gal \cdot in \cdot sec}$$

$$= \frac{0.98 \cancel{\frac{gal}{min}}}{\left(\frac{\pi \cdot (.25)^2}{4}\right) \cancel{in^2}} \times .32083 \frac{\cancel{in^3} \cdot ft \cdot \cancel{min}}{\cancel{gal} \cdot \cancel{in} \cdot sec}$$

$$= 6.405\ ft/sec$$

$$V_{avg_{3/8}} = \frac{2.90 \cancel{\frac{gal}{min}}}{\left(\frac{\pi \cdot (0.375)^2}{4}\right) \cancel{in^2}} \times .32083 \frac{\cancel{in^3} \cdot ft \cdot \cancel{min}}{\cancel{gal} \cdot \cancel{in} \cdot sec}$$

$$= 8.424\ ft/sec$$

$$V_{avg_{1/2}} = \frac{6 \cancel{\frac{gal}{min}}}{\left(\frac{\pi \cdot (.500)^2}{4}\right) \cancel{in^2}} \times .32083 \frac{\cancel{in^3} \cdot ft \cdot \cancel{min}}{\cancel{gal} \cdot \cancel{in} \cdot sec}$$

$$= 9.804 \frac{ft}{sec}$$

$$Re = \frac{(\rho)(V_{avg})(D)}{\mu}$$

$$Re_{1/4} = \frac{\left(62.41 \frac{lbm}{\cancel{ft^3}}\right)\left(6.405 \frac{ft}{\cancel{sec}}\right)\left(.25 \cancel{in}\right)\left(\frac{1 ft}{12 \cancel{in}}\right)}{\left(8.781 \times 10^{-4} \frac{\cancel{lbm}}{\cancel{ft \cdot sec}}\right)}$$

$= 9483.9 \therefore$ Flow is turbulent

$$Re_{3/8} = \frac{\left(62.41 \frac{lbm}{\cancel{ft^3}}\right)\left(8.424 \frac{ft}{\cancel{sec}}\right)\left(.375 \cancel{in}\right)\left(\frac{1 ft}{12 \cancel{in}}\right)}{\left(8.781 \times 10^{-4} \frac{lbm}{\cancel{ft \cdot sec}}\right)}$$

$= 18710.2 \therefore$ Flow is turbulent

$$Re_{1/2} = \frac{\left(62.41 \frac{lbm}{\cancel{ft^3}}\right)\left(9.804 \ ft/sec\right)\left(.500 \cancel{in}\right)\left(\frac{1 ft}{12 \cancel{in}}\right)}{\left(8.781 \times 10^{-4} \frac{lbm}{\cancel{ft \cdot sec}}\right)}$$

$= 29033.7 \therefore$ Flow is turbulent

$$\left(\frac{\varepsilon}{D}\right)_{1/4} = \frac{.00006 \cancel{in}}{.25 \cancel{in}} = .00024$$

$$\left(\frac{\varepsilon}{D}\right)_{3/8} = \frac{.00006 \cancel{in}}{.375 \cancel{in}} = .0016$$

$$\left(\frac{\varepsilon}{D}\right)_{1/2} = \frac{.00006 \cancel{in}}{.500 \cancel{in}} = .00012$$

From Appendix 1, Figure A-27. Select values of Darcy friction factor, f, for calculated relative roughness, $\frac{\varepsilon}{D}$, and Reynold's number, Re.

$$f_{1/4} \approx .031$$

$$f_{3/8} \approx .0275$$

$$f_{1/2} \approx .0235$$

$$\Delta P = \Delta P_L = f \frac{L}{D} \frac{\rho V^2}{2} \Rightarrow L = \frac{(\Delta P_L)(2)(D)}{(\rho)(V^2)(f)}$$

Assume an inlet pressure of 40 psia from the garden hose and a desired outlet pressure of 5 psia $\therefore \Delta P_L = 40 - 5 = 35$ psia.

max length

$$L_{1/4} = \frac{\left(35 \frac{\cancel{lbf}}{\cancel{in^2}}\right)(2)\left(.25\ \cancel{in}\right)\left(\frac{32.2\ \cancel{lbm} \cdot \frac{ft}{\cancel{s^2}}}{1\ \cancel{lbf}}\right)\left(\frac{12\ \cancel{in}}{1\ \cancel{ft}}\right)}{\left(62.41 \frac{\cancel{lbm}}{\cancel{ft^3}}\right)\left(6.405\right)^2 \frac{\cancel{ft^2}}{\cancel{s^2}}\left(.031\right)}$$

$$= 85.126\ ft$$

$$L_{3/8} = \frac{\left(35 \frac{\cancel{lbf}}{\cancel{in^2}}\right)(2)\left(.375\ \cancel{in}\right)\left(\frac{32.2\ \cancel{lbm} \cdot \cancel{ft}/\cancel{s^2}}{1\ \cancel{lbf}}\right)\left(\frac{12\ \cancel{in}}{1\ \cancel{ft}}\right)}{\left(62.41 \frac{\cancel{lbm}}{\cancel{ft^3}}\right)\left(8.424\right)^2 \frac{\cancel{ft^2}}{\cancel{sec^2}}\left(.0275\right)}$$

$$= 83.280\ ft$$

$$L_{1/2} = \frac{\left(35 \frac{\cancel{lbf}}{\cancel{in^2}}\right)(2)\left(.500\ \cancel{in}\right)\left(\frac{32.2\ \cancel{lbm} \cdot \frac{\cancel{ft}}{\cancel{s^2}}}{1\ \cancel{lbf}}\right)\left(\frac{12\ \cancel{in}}{1\ \cancel{ft}}\right)}{\left(62.41 \frac{\cancel{lbm}}{\cancel{ft^3}}\right)\left(9.804 \frac{\cancel{ft}}{\cancel{sec}}\right)^2\left(.0235\right)}$$

$$= 95.935\ ft$$

1 gallon = 8.33 lbm of water

$$\dot{Q} = \dot{m}\, C_p\, \Delta T$$

$$\dot{Q}_{1/4} = \left(1.000 \frac{BTU}{\cancel{lbm}\cdot\cancel{R}}\right)\left(190\cancel{°F} - 50\cancel{°F}\right)\left(0.98 \frac{\cancel{gal}}{min}\right)\left(8.33 \frac{\cancel{lbm}}{\cancel{gal}}\right)$$

$$= 1142.9 \frac{BTU}{min} = 19.048\ BTU/s = 68574\ BTU/hr$$

$$\dot{Q}_{3/8} = \left(1.000 \frac{BTU}{\cancel{lbm}\cdot\cancel{R}}\right)\left(190 - 50\cancel{°F}\right)\left(2.9 \frac{\cancel{gal}}{min}\right)\left(\frac{8.33\ \cancel{lbm}}{1\ \cancel{gal}}\right)$$

$$= 3382\ BTU/min = 56.366\ BTU/s = 202920\ BTU/hr$$

$$\dot{Q}_{1/2} = \left(1.000 \frac{BTU}{\cancel{lbm}\cdot\cancel{R}}\right)\left(190 - 50\ \cancel{°F}\right)\left(6 \frac{\cancel{gal}}{min}\right)\left(\frac{8.33\ \cancel{lbm}}{1\ \cancel{gal}}\right)$$

$$= 6997.2\ BTU/min = 116.6\ BTU/s = 419832\ BTU/hr$$

Finding req'd length w/ energy to heat water

$$\dot{Q} = UA_s\Delta T, \quad A_s = \pi d L$$

$$\therefore$$

$$\dot{Q} = U\pi d L \Delta T \Rightarrow L = \frac{\dot{Q}}{U\pi \cdot d \cdot \Delta T}$$

L = Length of piping

d = diameter of piping

ΔT = change in temperature

~~From experiment done,~~ $\overset{\text{assumption}}{U = 110 \ \frac{BTU}{hr \cdot ft^2 \cdot °F}}$

$$L'_{1/4} = \frac{\dot{Q}_{1/4}}{(U)(\pi)(d_{1/4})\Delta T} ;$$

$\Delta T = 190 - 50\ °F = 140°F$

$\dot{Q}_{1/4} = 68574 \ \frac{BTU}{hr}$

$\dot{Q}_{3/8} = 202920 \ BTU/hr$

$\dot{Q}_{1/2} = 419832 \ BTU/hr$

$$= \frac{68574 \ \frac{BTU}{\cancel{hr}}}{(\pi)(.25\cancel{in})(140\cancel{°F})\left(110 \frac{\cancel{BTU}}{\cancel{hr} \cdot ft^2 \cdot \cancel{°F}}\right)\left(\frac{1 ft}{12 \cancel{in}}\right)}$$

$= 68.03^{ft}$

$$L'_{3/8} = \frac{\dot{Q}_{3/8}}{(U)(\pi)(d_{3/8})(\Delta T)} = \frac{202920 \ \frac{\cancel{BTU}}{\cancel{hr}}}{\left(110 \frac{\cancel{BTU}}{\cancel{hr} \cdot ft^2 \cdot \cancel{°F}}\right)(\pi)(.375\cancel{in})\left(\frac{1 ft}{12 \cancel{in}}\right)(140\cancel{°F})}$$

$= 134.22^{ft}$

$$L'_{1/2} = \frac{\dot{Q}_{1/2}}{(U)(\pi)(d_{1/2})(\Delta T)} = \frac{419832 \ \frac{\cancel{BTU}}{\cancel{hr}}}{\left(110 \frac{\cancel{BTU}}{\cancel{hr} \cdot ft^2 \cdot \cancel{°F}}\right)(\pi)(.500 in)\left(\frac{1 \cancel{ft}}{12 \cancel{in}}\right)(140\cancel{°F})}$$

$= 208.26^{ft}$

Given:

- $D = \frac{1}{4}in, \frac{3}{8}in, \frac{1}{2}in$

flow rate. = 0.5 gpm, 1.0 gpm, 1.5 gpm, 3.0 gpm

- $\Delta P_L = 35\ psi$
- $U = 110\ \frac{BTU}{hr \cdot ft^2 \cdot {}^\circ F}$

Find:

$\dot{Q}$ for each flow rate & L for each diameter of each flow rate rate.

Soln:

~~$\dot{Q}_{1/4}$~~ @ 0.5 gpm

$$\dot{Q}_{\cancel{1/4}} = \dot{m}\ C_p\ \Delta T$$

$$\dot{Q}_{0.5gpm} = \left(1.000\ \frac{BTU}{\cancel{lb_m} \cdot \cancel{R}}\right)\left(190^\circ F - 50^\circ F\right)\left(0.5\ \frac{\cancel{gal}}{\cancel{min}}\right)\left(\frac{8.33\ \cancel{lb_m}}{1\ \cancel{gal}}\right)\left(\frac{60\ \cancel{min}}{1\ hr}\right)$$

$$= \boxed{34986\ BTU/hr}$$

$$\dot{Q}_{1.0gpm} = \left(1.000\ \frac{BTU}{\cancel{lb_m} \cdot \cancel{R}}\right)\left(190 - 50\ \cancel{{}^\circ F}\right)\left(1.0\ \frac{\cancel{gal}}{\cancel{min}}\right)\left(\frac{8.33\ \cancel{lb_m}}{1\ \cancel{gal}}\right)\left(\frac{60\ \cancel{min}}{1\ hrs}\right)$$

$$= \boxed{69972\ BTU/hr}$$

$$\dot{Q}_{1.5\ gpm} = \left(1.00\ \frac{BTU}{lb_m \cdot R}\right)\left(190 - 50^\circ F\right)\left(1.5\ \frac{gal}{min}\right)\left(\frac{8.33\ lb_m}{1\ gal}\right)\left(\frac{60\ min}{1\ hr}\right)$$

$$= \boxed{104958\ BTU/hr}$$

$$\dot{Q}_{3.0gpm} = \left(1.00\ \frac{BTU}{lb_m \cdot R}\right)\left(190 - 50^\circ F\right)\left(3.0\ \frac{gal}{min}\right)\left(\frac{8.33\ lb_m}{1 gal}\right)\left(\frac{60\ min}{1\ hr}\right)$$

$$= \boxed{209916\ BTU/hr}$$

$\dot{Q}_{0.5gpm} = 34986 \frac{BTU}{hr}$

$\dot{Q}_{1.0gpm} = 69972 \frac{BTU}{hr}$

$\dot{Q}_{1.5gpm} = 104958 \frac{BTU}{hr}$

$\dot{Q}_{3.0gpm} = 209916 \frac{BTU}{hr}$

$U = 110 \frac{BTU}{hr \cdot ft^2 \cdot °F}$

$d_{1/4} = 0.25^{in} \times \frac{1ft}{12in} = .02083^{ft}$

$d_{3/8} = .375^{in} \times \frac{1ft}{12in} = .03125^{ft}$

$d_{1/2} = .500^{in} \times \frac{1ft}{12in} = .04167^{ft}$

$\Delta T = 190 - 50°F = 140°F$

Length @ varying gpm's

$$\dot{Q} = UA_s\Delta T;\quad A_s = \pi d L$$

$$\dot{Q} = U(\pi d L)(\Delta T) \Rightarrow L = \frac{\dot{Q}}{U \cdot \pi \cdot d \cdot \Delta T}$$

$L_{1/4}$ @ 0.5 gpm

$$L_{1/4} = \frac{\dot{Q}_{0.5gpm}}{U\pi d_{1/4}\Delta T} = \frac{34986\ BTU/\cancel{hr}}{\left(110 \frac{\cancel{BTU}}{\cancel{hr \cdot ft^2 \cdot °F}}\right)(\pi)(.02083^{ft})(140°\cancel{F})}$$

$$= \boxed{34.71^{ft}}$$

$L_{1/4}$ @ 1.0 gpm

$$L = \frac{\dot{Q}_{1.0gpm}}{U\pi d_{1/4}\Delta T} = \frac{69972 \frac{BTU}{\cancel{hr}}}{\left(110 \frac{BTU}{\cancel{hr \cdot ft^2 \cdot °F}}\right)(\pi)(.02083^{ft})(140°\cancel{F})}$$

$$= \boxed{69.42^{ft}}$$

$L_{1/4}$ @ 1.5 gpm

$$L = \frac{\dot{Q}_{1.5gpm}}{U \pi d_{1/4} \Delta T} = \frac{104958 \frac{BTU}{\cancel{hr}}}{\left(110 \frac{BTU}{\cancel{hr} \cdot ft^2 \cdot \cancel{°F}}\right)(\pi)(.02083\,ft)(140\,\cancel{°F})}$$

$$\boxed{= 104.13\,ft}$$

$L_{1/4}$ @ 3.0 gpm

$$L = \frac{\dot{Q}_{3.0gpm}}{U \pi d_{1/4} \Delta T} = \frac{209916 \frac{BTU}{\cancel{hr}}}{\left(110 \frac{BTU}{\cancel{hr} \cdot ft^2 \cdot \cancel{°F}}\right)(\pi)(.02083\,ft)(140\,\cancel{°F})}$$

$$\boxed{= 208.26\,ft}$$

$L_{3/8}$ @ 0.5 gpm

$$L = \frac{\dot{Q}_{0.5gpm}}{U \pi d_{3/8} \Delta T} = \frac{34986 \frac{BTU}{\cancel{hr}}}{\left(110 \frac{BTU}{\cancel{hr} \cdot ft^2 \cdot \cancel{°F}}\right)(\pi)(.03125\,ft)(140\,\cancel{°F})}$$

$$\boxed{= 23.14\,ft}$$

$L_{3/8}$ @ 1.0 gpm

$$L = \frac{\dot{Q}_{1.0gpm}}{U \pi d_{3/8} \Delta T} = \frac{69972 \frac{BTU}{\cancel{hr}}}{\left(110 \frac{BTU}{\cancel{hr} \cdot ft^2 \cdot \cancel{°F}}\right)(\pi)(.03125\,ft)(140\,\cancel{°F})}$$

$$\boxed{= 46.28\,ft}$$

$L_{3/8}$ @ 1.5 gpm

$$L = \frac{\dot{Q}_{1.5gpm}}{U \pi d_{3/8} \Delta T} = \frac{104958 \ \text{BTU/hr}}{\left(110 \frac{\text{BTU}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}\right)(\pi)(.03125 \ \text{ft})(140 \ {}^\circ\text{F})}$$

$$\boxed{= 69.42 \ \text{ft}}$$

$L_{3/8}$ @ 3.0 gpm

$$L = \frac{\dot{Q}_{3.0gpm}}{U \pi d_{3/8} \Delta T} = \frac{209916 \ \text{BTU/hr}}{\left(110 \ \text{BTU/hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}\right)(\pi)(.03125 \ \text{ft})(140 \ {}^\circ\text{F})}$$

$$\boxed{= 138.84 \ \text{ft}}$$

$L_{1/2}$ @ 0.5 gpm

$$L = \frac{\dot{Q}_{0.5gpm}}{U \pi d_{1/2} \Delta T} = \frac{34986 \ \text{BTU/hr}}{\left(110 \frac{\text{BTU}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}\right)(\pi)(.0416\dot{7} \ \text{ft})(140 \ {}^\circ\text{F})}$$

~~= 17.6~~

$$\boxed{= 17.36 \ \text{ft}}$$

$L_{1/2}$ @ 1.0 gpm

$$L = \frac{\dot{Q}_{1.0\,gpm}}{U \pi d_{1/2} \Delta T} = \frac{69972\ \cancel{BTU/hr}}{\left(110 \frac{\cancel{BTU}}{\cancel{hr} \cdot ft^{\cancel{2}} \cdot \cancel{°F}}\right)(\pi)(.04167\ \cancel{ft})(140\ \cancel{°F})}$$

$$\boxed{= 34.71\ ft}$$

$L_{1/2}$ @ 1.5 gpm

$$L = \frac{\dot{Q}_{1.5\,gpm}}{U \pi d_{1/2} \Delta T} = \frac{104958\ BTU/hr}{\left(110 \frac{BTU}{hr \cdot ft^2 \cdot °F}\right)(\pi)(.04167\ ft)(140\ °F)}$$

$$\boxed{= 52.07\ ft}$$

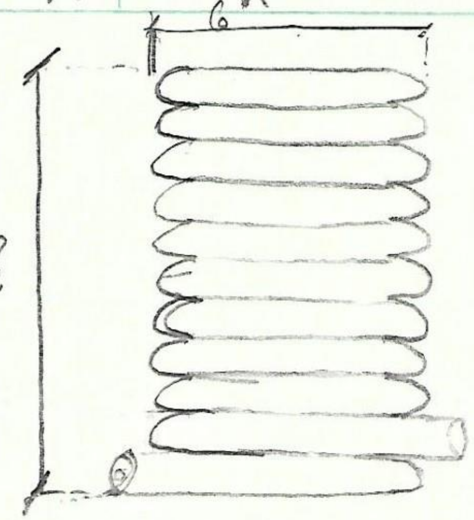
$L_{1/2}$ @ 3.0 gpm

$$L = \frac{\dot{Q}_{3.0\,gpm}}{U \pi d_{1/2} \Delta T} = \frac{209916\ \frac{\cancel{BTU}}{\cancel{hr}}}{\left(110 \frac{\cancel{BTU}}{\cancel{hr} \cdot ft^{\cancel{2}} \cdot \cancel{°F}}\right)(\pi)(.04167\ \cancel{ft})(140\ \cancel{°F})}$$

$$\boxed{= 104.13\ ft}$$

Choose 1/2 in copper pipe w/ length of 20ft

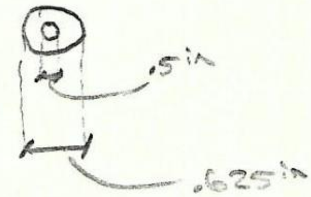
Hunter Arnold | Senior Project 12/7 | A-12



Given:
- Copper piping, $L = 20^{ft}$
- $d = .5^{in}$
- $D = .625^{in}$
- Diameter of coils $= 6^{in} = D_{coil}$

Find:
- Height of coiled piping

Soln:



$$C_{coil} = \text{Circumference}_{coil} = \pi D_{coil}$$

$$= \pi (6^{in}) \left(\frac{1 ft}{12 in}\right) = 1.571 \frac{ft}{coil}$$

$$\frac{\text{height}}{\text{coil}} = OD_{pipe} = .625 \cancel{in} \times \left(\frac{1 ft}{12 \cancel{in}}\right) = .05208^{ft}$$

$$\# \text{ of coils} = \frac{L_{pipe}}{C_{coil}} = \frac{20^{ft}}{1.571 \frac{ft}{coil}} = 12.73 \text{ coils}$$

to get # of coils to = 13 use

$$13_{coils} \cdot C_{coil} = L_{pipe}$$

$$13 \cancel{coils} \times 1.571 \frac{ft}{\cancel{coil}} = 20.423^{ft}$$

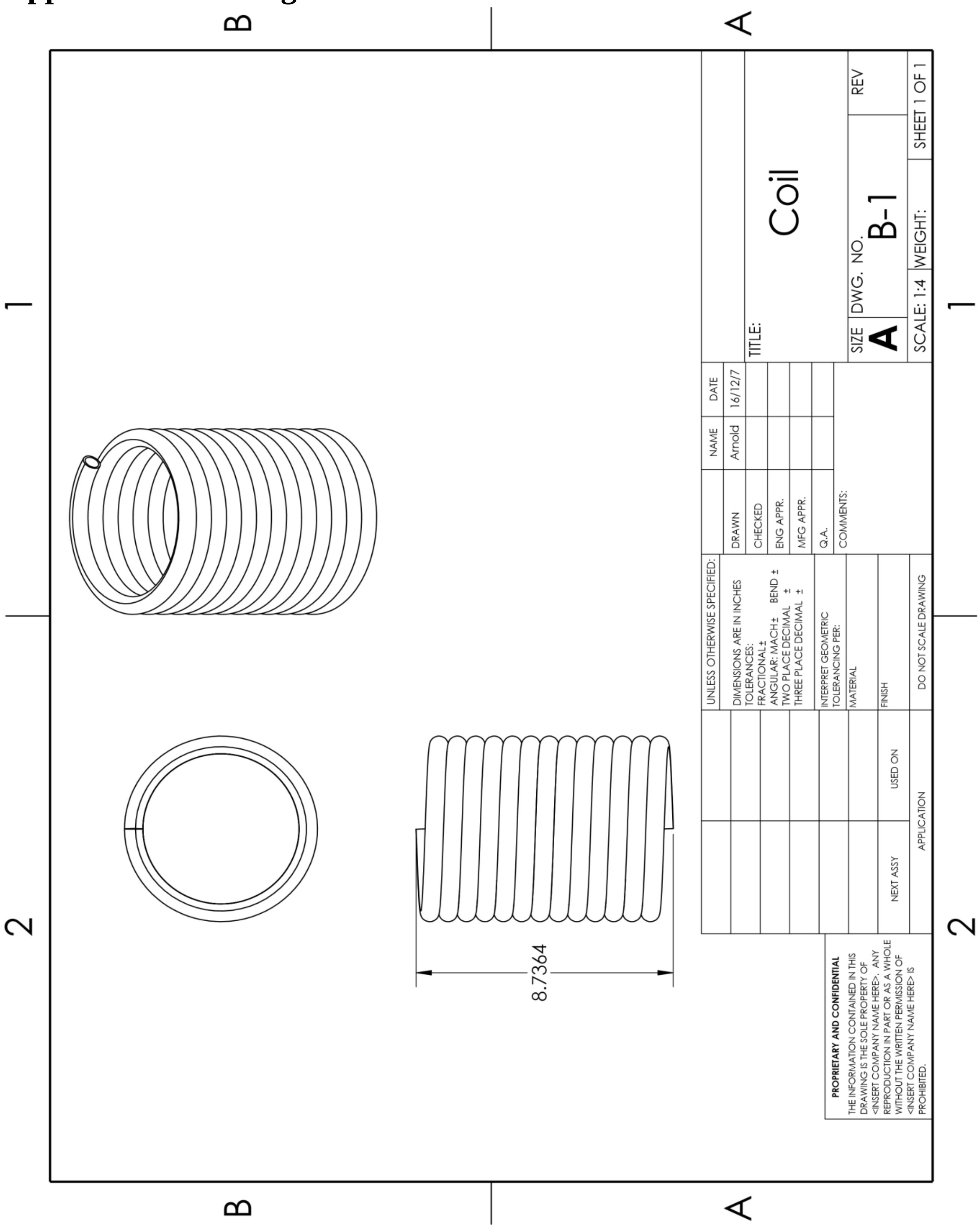
new length of piping is 20.423^{ft} w/ 13 coils

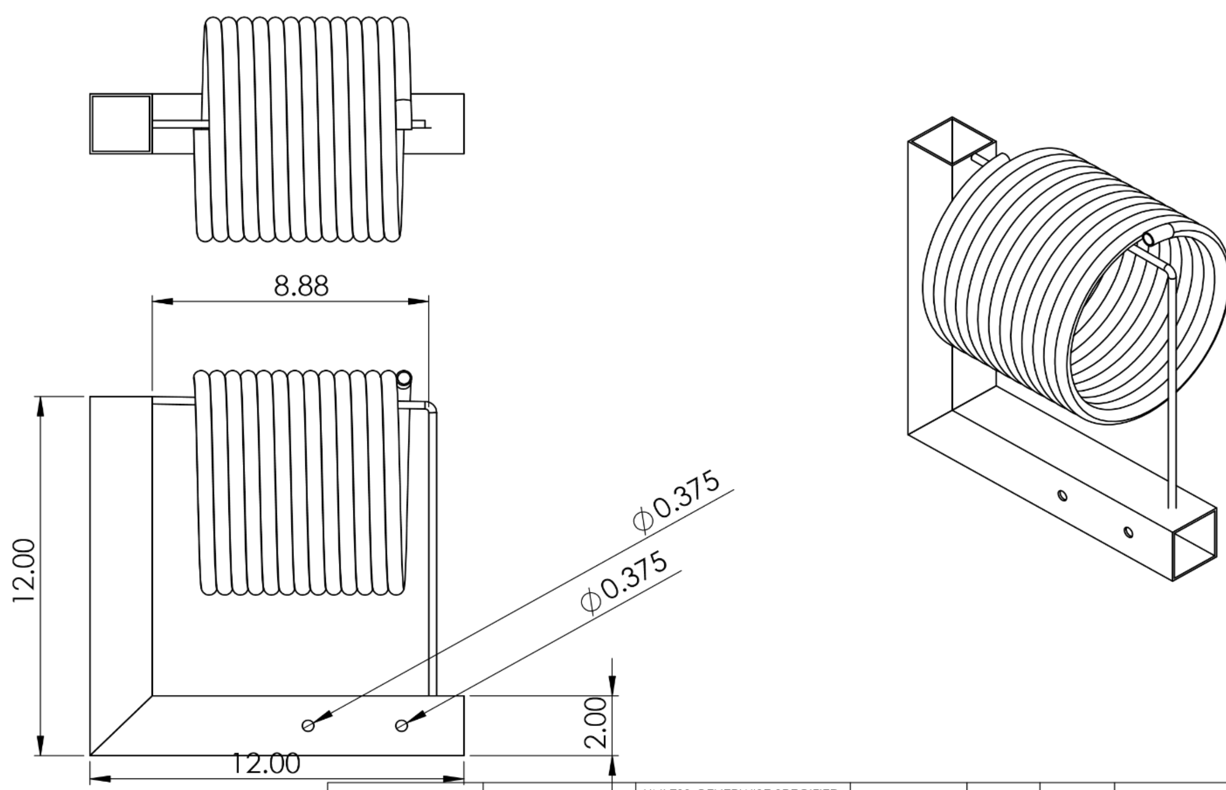
$$\text{height of coiled piping} = (\# \text{ of coils}) \times \left(\frac{\text{height}}{\text{coil}}\right)$$

$$= 13 \cancel{coils} \times .05208 \frac{ft}{\cancel{coil}} = .67708 \cancel{ft} \times \left(\frac{12 in}{\cancel{ft}}\right)$$

$$\boxed{h = 8.124^{in}}$$

Appendix B-Drawings





	UNLESS OTHERWISE SPECIFIED:		NAME	DATE		
	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN			TITLE:	
		CHECKED			Assembly	
		ENG APPR.				
		MFG APPR.				
	INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
	MATERIAL	COMMENTS:			SIZE A	DWG. NO. B-2 · REV
NEXT ASSY · USED ON	FINISH					
APPLICATION	DO NOT SCALE DRAWING				SCALE: 1:5 · WEIGHT:	SHEET 1 OF 1

Appendix C-Parts List

<u>Drawing Tree, Drawing ID's</u>

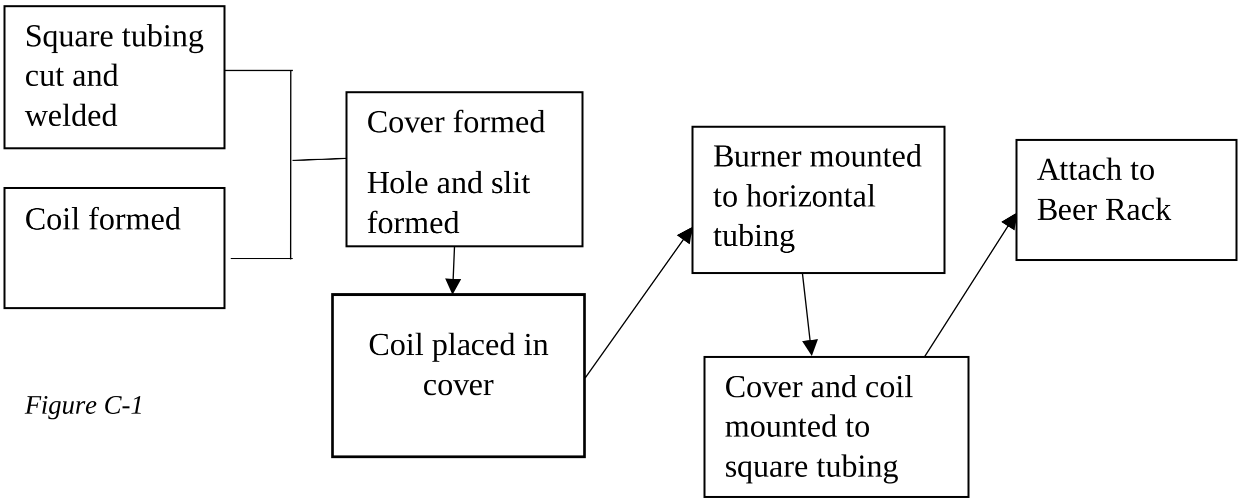


Figure C-1

Parts list and labels

Item ID	Description	Source
1	Coiled Copper Piping	Lowe's
2	Burner	morebeer.com
3	Stove Pipe Cover	Home Depot
4	3/8-in Ball Valve	Ace Hardware
5	Propane	Fred Meyer
6	Temperature Sensor	CWU
7	3/8-in Compression Fitting	Arnold's Home and Ranch
8	1/2-in Hose Adapter	McClendon Hardware
9	2 inch aluminum square tubing (1ft long)	Online Metals
10	Nipple Brass Hex 1/2x3/8	McClendon Hardware
11	1/4-in Hillman 3-Count Standard Hex Tap Bolt	Lowe's
12	Hillman 1/4-in x 3/4-in Zinc Plated Standard Flat Washer	Lowe's
13	Hillman 1/4-in Standard Split Lock Washer	Lowe's
14	1/4-in Zinc Plated Standard Hex Nut	Lowe's
15	5/16-in x 3-in Hillman Standard Hex Bolt	Lowe's
16	5/16-in Hillman Zinc Plated Standard Flat Washer	Lowe's
17	Hillman 5/16-in Standard Split Lock Washer	Lowe's
18	Hillman 5/16-in Zinc Plated Hex Nut	Lowe's
19	One Gallon Bucket	Self-Provided

Figure C-2

Appendix D-Budget

Item ID	Description	Source	Quantity	Cost per unit	Total Cost
1	Coiled Copper Piping	Lowe's	1	$47.00	$47.00
2	Burner	morebeer.com	1	$17.99	$17.99
3	Stove Pipe Cover	Home Depot	1	$69.00	$69.00
4	3/8-in Ball Valve	Ace Hardware	2	$9.99	$19.98
5	Propane	Fred Meyer	1	$20.00	$20.00
6	Temperature Sensor	CWU	1	$11.00	$11.00
7	3/8-in Compression Fitting	Arnold's Home and Ranch	2	$2.99	$5.98
8	1/2-in Hose Adapter	McClendon Hardware	1	$4.99	$4.99
9	2 inch aluminum square tubing (1ft long)	Online Metals	3	$12.28	$36.84
10	Nipple Brass Hex 1/2x3/8	McClendon Hardware	1	$5.49	$5.49
11	1/4-in Hillman 3-Count Standard Hex Tap Bolt	Lowe's	2	$1.52	$3.04
12	Hillman 1/4-in x 3/4-in Zinc Plated Standard Flat Washer	Lowe's	4	$0.12	$0.48
13	Hillman 1/4-in Standard Split Lock Washer	Lowe's	2	$0.16	$0.32
14	1/4-in Zinc Plated Standard Hex Nut	Lowe's	6	$0.06	$0.36
15	5/16-in x 3-in Hillman Standard Hex Bolt	Lowe's	2	$0.31	$0.62
16	5/16-in Hillman Zinc Plated Standard Flat Washer	Lowe's	4	$0.13	$0.52
17	Hillman 5/16-in Standard Split Lock Washer	Lowe's	2	$0.36	$0.72
18	Hillman 5/16-in Zinc Plated Hex Nut	Lowe's	2	$0.16	$0.32
19	One Gallon Bucket	Self Provided	1	$5.00	$5.00
				Total Cost:	$249.65

Table D-1

Appendix E-Schedule

Task ID:	Description	Duration (hours)	October	Novemver	December	January	February	March	April	May	June
1	**Proposal***	43			7-Dec						
1A	Outline	1	10-Oct								
1B	Introduction	2	17-Oct								
1C	Methods	2	24-Oct								
1D	Analysis	8	31-Oct								
1E	Discussion	5		7-Nov							
1F	Parts&Budget	3		14-Nov							
1G	Drawings	10			5-Dec						
1H	Schedule	2			6-Dec						
1I	Summary&Appendix	10			6-Dec						
2	**Manufature Plan**	26					2-Feb				
2A	Research/Order Parts	8						17-Mar			
2B	Cut and Weld Steel Tubing	3					18-Feb				
2C	Form Coil	2					22-Feb				
2D	Form Cover	4						2-Mar			
2E	Holes Drilled in Cover and Steel Tube	2						18-Mar			
2F	Coil Placed in Cover and Adjusted to Stay Off Cover	2						24-Mar			
2G	Burner Mounted on Steel Square Tube	3						24-Mar			
2H	Coil/Cover mounted to Steel Square Tube	2						24-Mar			
3	**Device Completed**	45						24-Mar			
4	**Test Plan**	10							19-Apr		
5	**Device Evaluated**	15								14-May	
5A	Water Temperature Test									7-May	
5B	Flow Rate Test									14-May	
6	**Project Report**	20									9-Jun
	Total Hours Estimated:	159									

Figure E-1

Appendix F-Expertise and Resources

Tiago Sousa and Stefan Schacht helped with welding the steel square tubing. Scott Cunningham and Jim Arnold helped with the construction of the coils, cover and assembly of the device.

Appendix G-Evaluation Sheet

Trial	Time (s)	Convert(GPM)	Temperature (F)
1			
2			
3			
4			
5			
Average:			

Table G-1

Appendix H-Testing Report

1. Clamp the device to the table. The side parallel with and furthest away from the heater should be clamped.
2. Place the outlet tube into the large bucket.
3. Connect the hose to the inlet of the copper piping.
4. Connect the burner to the propane tank.
5. With both ball valves all the way open, turn on the water from the hose.
6. Open the valve for the propane and open the valve for the burner as well. (Make sure the maximum amount of air flow is allowed into the burner by adjusting the plate at the end of the burner.
7. Light the burner through the opening where the coils are seen.
8. Once the burner has been lit, time how long it takes the water to heat to the desired temperature range of 170F-180F.
9. Adjust the ball valves to dial down the flow rate of the water until the desired temperature is reached. Do not shut the inlet ball valve and make sure enough water is flowing through the coils to ensure some flow out of the outlet pipe.
10. Using the thermometer, measure the temperature of the outlet water.
11. Turn off the burner, close the propane tank and let the device cool for at least two hours.
12. Repeat steps 1-11 four more times.

Safety:

Safety glasses should be worn at all times during the test of this device. Use caution when lighting the burner so injury does not occur.

Test 2: Output Flow Rate

The test will take a maximum of five minutes after initial set up is complete.

Along with the Instant Hot Water Heater, a table that can withstand high heat temperatures, a metal clamp, a propane tank, a lighter, a hose that supplies water, a one-gallon bucket and a timer will be used to run and test the device.

Steps:

1. Clamp the device to the table. The side parallel with and furthest away from the heater should be clamped.
2. Place the outlet tube into the large bucket.
3. Connect the hose to the inlet of the copper piping.
4. Connect the burner to the propane tank.
5. With both ball valves all the way open, turn on the water from the hose.
6. Open the valve for the propane and open the valve for the burner as well. (Make sure the maximum amount of air flow is allowed into the burner by adjusting the plate at the end of the burner.
7. Light the burner through the opening where the coils are seen.

8. Adjust the ball valves to dial down the flow rate of the water until the desired temperature is reached. Do not shut the inlet ball valve and make sure enough water is flowing through the coils to ensure some flow out of the outlet pipe.
9. Once the desired temperature is reached, empty the one gallon bucket and time how long it takes to fill the one gallon bucket completely in seconds. Convert this number from seconds to minutes to get the flow rate in gallons per minute.
10. Repeat step 9 four more times at different temperatures while still staying within the 170F-180F temperature range.

Appendix I-Testing Data

Trial	Time (s)	Convert(GPM)	Temperature (F)
1	119	0.5042	180
2	110	0.5455	171
3	118	0.5085	178
4	115	0.5217	173
5	118	0.5085	177
Average:	116	0.5177	175.8

Table I-1

Appendix J-Resume

Hunter E. Arnold

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Auburn, WA 98092-3190

Phone: 206-300-7423

E-mail: harnold1018@gmail.com

Education

September 2014— Current, Undergraduate Studies, Central Washington University

- Majoring in Mechanical Engineering Technology

September 2013—June 2014, Undergraduate Studies, Oregon State University

September 2009– June 2013, High School Diploma, Auburn Mountainview High School

Work Experience

- March 2012—September 2013
  - Auburn District Pool, Water Polo Instructor

    - I ran sessions at the Auburn Pool where I instructed middle school and high school students on how to play water polo.
- March 2012 - March 2013
    - Seattle Sounders/Seattle Seahawks
    - I sold merchandise at Seattle Sounders and Seattle Seahawks games. In addition, I ran the cash register, stocked apparel and closed the accounts at the end of the shift.
- August 2014 – September 2015
    - Kent Swim and Tennis Club, Water Polo Coach
    - I was Head Water Polo coach for the Kent Swim & Tennis Club for the 2014 and 2015 seasons.
- December 2015 (Seasonal)
    - BBSI for Plush Pippin Pies
    - I was responsible for the yearend inventory for the company financials.

Leadership/Volunteer Work

- **Eagle Scout Project**, Auburn Youth Resources (set up and built garden and playground area for new daycare)
- **Auburn Dream Center** with Auburn Mountainview Water Polo team and Boeing Leadership group (sorting donated food and delivering to local homes)
- **Auburn Mountainview Booster Club** (helped with set up of various Booster Club fundraising activities)

Awards

Boys Scouts of America, 2012

- Eagle Scout

Auburn Mountainview High School, 2010-2012

- Captain, Boys Water Polo (3 years)
- Captain, Boys Swim & Dive team (2 years)
- Coaches Award, Boys Water Polo (2 years)
- Lifetime Achievement Award, Boys Water Polo

Dean's List

- Central Washington University, 2014-2015

References

Michelle Scheurman, Seahawks/Sounders Manager, (253) 653-3514

Justin Pritchard, Coach/Teacher, (253) 347-1942

Tom Lempert, Board President, (253) 740-8628

John Childress, P.E., Boeing Sr. Manager, (206) 595-6274